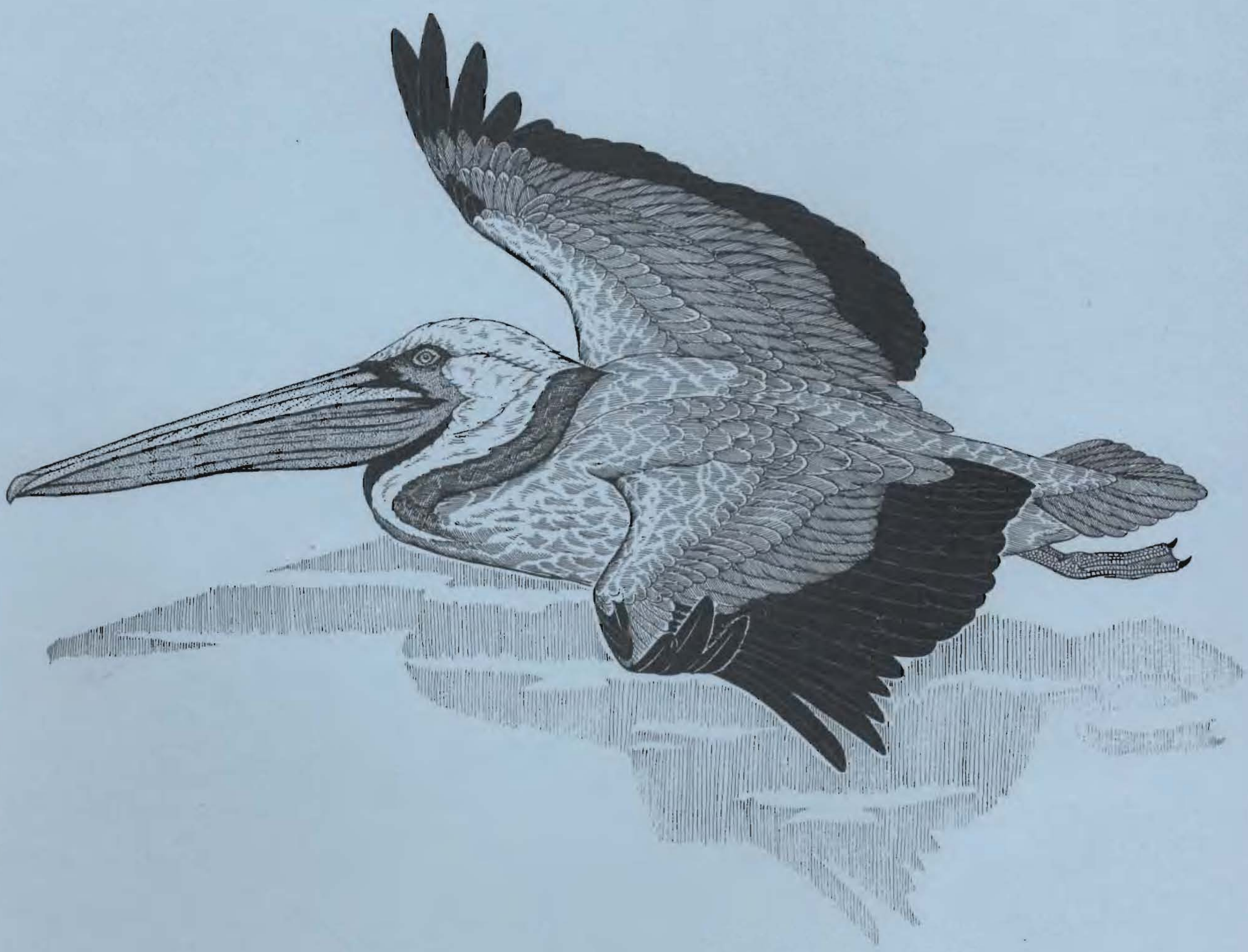
Biological Report 82(10.90)
May 1985

HABITAT SUITABILITY INDEX MODELS: EASTERN BROWN PELICAN



Fish and Wildlife Service

Department of the Interior

This model is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

This is one of the first reports to be published in the new "Biological Report" series. This technical report series, published by the Research and Development branch of the U.S. Fish and Wildlife Service, replaces the "FWS/OBS" series published from 1976 to September 1984. The Biological Report series is designed for the rapid publication of reports with an application orientation, and it continues the focus of the FWS/OBS series on resource management issues and fish and wildlife needs.

MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. It is impossible, however, to develop a model that performs equally well in all situations. Each model is published individually to facilitate updating and reprinting as new information becomes available. Assistance from users and researchers is an important part of the model improvement process. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to the following address.

National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Thank you for your assistance.

Species________________ Geographic Location______________________________________

Habitat or Cover Type(s)______________________________________

Type of Application: Impact Analysis____ Management Action Analysis__________
Baseline_______ Other______________________________________

Variables Measured or Evaluated______________________________________

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Was the species information useful and accurate? Yes___ No___

If not, what corrections or improvements are needed?______________________

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Were the variables and curves clearly defined and useful? Yes____ No____

If not, how were or could they be improved?________________________________

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Were the techniques suggested for collection of field data:

Appropriate? Yes____ No____

Clearly defined? Yes____ No____

Easily applied? Yes____ No____

If not, what other data collection techniques are needed?__________________

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Were the model equations logical? Yes____ No____

Appropriate? Yes____ No____

How were or could they be improved?____

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Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information)____________________________________

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Additional references or information that should be included in the model:

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Model Evaluator or Reviewer______________________Date______________________

Agency____

Address____

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Telephone Number Comm:________________________ FTS______________________

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HABITAT SUITABILITY INDEX MODELS: EASTERN BROWN PELICAN

by

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PREFACE

The eastern brown pelican habitat suitability index (HSI) model is intended for use in the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980) for impact assessment and habitat management. The model was developed from a review and synthesis of existing information and is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions involved in developing the HSI model and guidelines for model applications, including methods for measuring model variables, are described.

This model is a hypothesis of species-habitat relationships, not a statement of proven cause and effect. The model has not been field-tested. For this reason, the U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that may help increase the utility and effectiveness of this habitat-based approach to fish and wildlife management. Please send any comments and suggestions you may have on the HSI model to the following address.

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index model for the eastern brown pelican was reviewed and constructively criticized by Erwin E. Klaas and Jaime A. Collazo, Iowa Cooperative Wildlife Research Unit, Iowa State University, Ames; Steven A. Nesbitt, Florida Game and Fresh Water Fish Commission, Wildlife Research Laboratory, Gainesville; Ralph W. Schreiber, Museum of Natural History, Los Angeles, California; David J. Wesley, Endangered Species Field Office, U.S. Fish and Wildlife Service (FWS), Jacksonville, Florida; Lovett E. Williams, Jr., Florida Game and Fresh Water Fish Commission, Wildlife Research Laboratory, Gainesville; and Don A. Wood, Florida Game and Fresh Water Fish Commission, Tallahassee. Thorough evaluations of model structure and functional relationships were provided by personnel of the FWS National Coastal Ecosystems Team (NCET). Supportive narrative and model reviews also were provided by Regional personnel of the FWS. Funding for model development and publication was provided by the FWS. The cover illustration was prepared by Patrick J. Lynch.

EASTERN BROWN PELICAN (*Pelecanus occidentalis carolinensis*)

INTRODUCTION

Brown pelicans (*Pelecanus occidentalis*) are large marine birds (3.5 kg or 7.7 lb) with a wingspan of 2 m (6.6 ft) that prey on fish by plunge-diving. Two brown pelican subspecies occur along coastal regions of the continental United States (Wetmore 1945). The eastern brown pelican (*P. o. carolinensis*) is found along the Atlantic coast from North Carolina to Florida and along the entire gulf coast to northern South America; it also ranges along the Pacific coast from southern Mexico to Columbia. The California brown pelican (*P. o. californicus*) is found along the Pacific coast from Washington south into Mexico. The eastern subspecies is smaller, with a wingchord averaging 25 mm (1 inch) shorter (526 mm or 21 inches total length) than the California subspecies, and has lighter breeding plumage on the hindneck (Wetmore 1945). This habitat suitability index model applies only to the eastern brown pelican.

Dramatic declines in brown pelican populations have been observed twice during this century (King et al. 1977a). In the 1930's, brown pelicans were destroyed by fishermen in Texas and Louisiana because of presumed competition for commercial fish (Gustafson et al. 1939). Food habit studies since then have shown that commercially important fish species comprise only 1% to 10% of the brown pelican diet (Palmer 1962); consequently, these birds probably have little impact on the commercial fishery (see Anderson et al. 1980).

The decline in breeding populations in Texas and South Carolina has been attributed to disease, inclement weather, and pollution (Blus 1970; Schreiber and Risebrough 1972; King et al. 1977b). Organochlorines in the food chain have been implicated as the cause of eggshell thinning and lowered reproductive success since the late 1950's (Mount and Putnicki 1966; Anderson et al. 1975; Nesbitt et al. 1978; Blus et al. 1979a; Mendenhall and Prouty 1979; Blus 1982). The western subspecies of brown pelican experienced complete reproductive failure in California in 1969 (Risebrough et al. 1971), and the eastern subspecies was extirpated in Louisiana in the late 1950's and early 1960's (King et al. 1977a). Both subspecies were placed on the Federal Endangered Species List in 1970 (USNFWL 1980). A breeding population of eastern brown pelicans was reintroduced into Louisiana from Florida (Williams and Joanen 1974; Nesbitt et al. 1978). Eastern brown pelican populations have become stable or have even increased in the Southeastern United States under protection. The subspecies and its habitats in North and South Carolina, Georgia, Florida, and Alabama were recently removed from Endangered Species Act protection (U.S. Fish and Wildlife Service 1985).

Distribution

In the United States, the eastern brown pelican breeding range includes the Atlantic coast of North Carolina, South Carolina, and Florida and the gulf coast of Florida, Alabama, Louisiana, and Texas (Palmer 1962).

Along the Atlantic Coast in North Carolina, the brown pelican nesting population has been divided between Shell Castle and North Rock Islands or, in some years, between Beacon Island and Cape Fear River spoil islands (Williams 1979; Clapp et al. 1982; Donald McCrimmon, Cornell University Laboratory of Ornithology; pers. comm.). Two colonies occur in South Carolina, one on Deveaux Bank and one at Cape Romain National Wildlife Refuge (Mendenhall and Prouty 1979). On the Atlantic coast of Florida, the species nests from Port Orange in Volusia County to the Florida Keys (Nesbitt et al. 1982). Brown pelicans nest along the gulf coast of Florida from Cedar Key in Levy County south to the Florida Keys; exceptions are a colony in Bay County near Panama City and a former colony near Port St. Joe (Florida Game and Fresh Water Fish Commission 1984). Brown pelican nesting colonies in Florida have been mapped and numbered by Williams (1979). Breeding populations on Florida's Atlantic and gulf coasts tend to remain separate (Schreiber 1976b). Additional colonies along the gulf coast include one in Mobile Bay, Alabama, and two restored colonies in Louisiana, one on Queen Bess Island near Grand Terre, and one on an island near the northern Chandeleur Islands. Texas recently has had four colony sites from Matagorda Bay south to Corpus Christi Bay (Texas Parks and Wildlife Department 1983).

In 1983, at least 1,382 pairs of eastern brown pelicans bred in North Carolina (McCrimmon, pers. comm.), 4,919 pairs in South Carolina (Phillip Wilkinson, South Carolina Wildlife and Marine Resources Department; pers. comm.), 6,980 pairs in Florida (Florida Game and Fresh Water Fish Commission 1984), at least 500 pairs in Louisiana (Larry McNease, Louisiana Department of Wildlife and Fisheries; pers. comm.), and 96 pairs in Texas (Texas Parks and Wildlife Department 1983).

Locations of peak concentrations of nonbreeding eastern brown pelicans and breeding colony sites have been listed for the Atlantic (Osborn and Custer 1978; Portnoy et al. 1981; Nesbitt et al. 1982) and gulf coasts (Williams 1979; Clapp et al. 1982; Nesbitt et al. 1982; Texas Colonial Waterbird Society 1982; Keller et al. 1984).

Life History Overview

Eastern brown pelicans usually begin to breed when they are 3 to 5 years old (Williams and Joanen 1974; Blus and Keahey 1978); their longevity approaches 20 years (Clapp et al. 1982). They nest in colonies of 10 to 1,500 pairs, though colonies usually average several hundred pairs (Schreiber 1978). The nesting season can vary by more than a month from year to year and probably is related to patterns of unseasonably high or low temperatures (Schreiber 1980a). Brown pelicans often begin nesting in February on Florida's west coast and in December on the east coast and Florida Keys. Nesting in North and South Carolina and in Texas often begins in March (Schreiber 1980a).

Transplanted colony offspring in Louisiana have retained the nesting season timing of the source population from Florida. They nest several months earlier than the native population that was extirpated in Louisiana (Portnoy 1977).

Although most eggs are laid during the season's first 3 months, egg-laying can span 6 months with both fledglings and eggs present in mid- season (Schreiber 1979). The usual clutch size is three eggs. Production of young fledglings requires about 18 weeks, including 1 to 2 weeks for nest building. Pelicans begin a 30-day incubation period after laying the first egg, resulting in asynchronous hatching (Schreiber 1979) and a greater chance of fledging for the first hatchling (Schreiber 1976a). Both sexes attend the altricial young for 10 to 12 weeks (Schreiber 1979). Breeding success is dependent upon the foraging success of the adults and varies greatly from year to year (Schreiber 1979; Anderson et al. 1982). Factors, in addition to starvation, that cause reduced breeding success include flooding of nests, nest desertion due to heavy tick infestation, egg breakage caused by adult birds' flushing in response to human disturbance, and predation of disturbed, unattended nests (reviewed by Clapp et al. 1982). Survival of nestlings and fledglings, not clutch size or hatching success, is the major source of variation in annual productivity of brown pelicans. Highest nestling mortality occurs during the first 30 days after hatching (Schreiber 1979). Captive brown pelicans have re-layed up to three times in a season and within 1 to 3 months after the previous loss. Schreiber (1979) found that re-laying occurred in as many as 26% (N=23) of nests in wild colonies. Later attempts had lower hatching success but were more likely to fledge hatchlings (85% success, N=39) than nests with only initial clutches (52% success, N=610) (Schreiber 1979).

Postfledging mortality for the first year averages 69% to 76% and then declines to an annual mortality of 16% as the birds become more proficient at foraging (Henny 1972; Schreiber 1976b, 1978). After the nesting season, birds along the Atlantic coast disperse to the south along the Florida east coast to the Keys (Schreiber 1976b). Pelicans on the gulf coast also disperse southward, and many probably winter south of the United States (Schreiber and Schreiber 1983).

SPECIFIC HABITAT REQUIREMENTS

Food

Eastern brown pelican food habits vary within its breeding range. In South Carolina, brown pelicans feed almost exclusively on young Atlantic menhaden (*Brevoortia tyrannus*) found in coastal estuaries (Blus et al. 1979b). In Louisiana and Texas, 90% to 95% of the diet (weight or volume not specified) consists of gulf menhaden (*B. patronus*), mullet (*Mugil* sp.), and other species not considered sportfish (Pearson 1921; Krantz 1968). Fogarty et al. (1981) found that regurgitated food boluses of Florida nestlings consisted of 14% menhaden by weight, with the remainder comprising 28% Atlantic threadfin (*Polydactylus octonemus*), 17% mullet, 11% spot (*Leiostomus xanthurus*), and 8% pinfish (*Lagodon rhomboides*). Adults must supply about 57 kg (125 lb) of fish to each young before fledging and require about 90 kg (198 lb) for themselves during nesting (Schreiber 1976a, 1982). Indirect evidence from parasitological studies indicates that nestlings are fed progressively larger fish of greater diversity as they grow older and that fledglings along the Florida coast are heavily dependent on mullet while learning to feed (Humphrey et al. 1978).

Brown pelicans plunge-dive from heights of up to 20 m (66 ft) to capture prey with their bill and pouch (Schreiber et al. 1975). Percentage estimates of successful plunge-dives have ranged from 30% (Gunter 1958) to 84% (Schnell et al. 1983). The lowest estimate includes data from immatures, which tend to be less successful (10% to 20% less) than adults (Orians 1969; Schnell et al. 1983). Pelicans usually capture prey items less than 25 cm (10 inches) long, and most captures occur in the top 1 m (3.3 ft) of water (Krantz 1968; Schreiber 1979; Schnell et al. 1983). These birds are not suited for underwater pursuit of prey (Sivak et al. 1977) but can capture fish by scooping them up while swimming at the surface (Dinsmore 1974; Rodgers 1978). Brown pelicans will scavenge offal thrown from boats or fishing piers (Sefton 1950; Schreiber 1978).

Eastern brown pelicans forage primarily in shallow estuarine waters (Schreiber 1978) and in marine waters within 32 km (20 mi) of shore (Williams 1979). The western subspecies may feed regularly up to 175 km (105 mi) offshore and 75 km (45 mi) from the nearest island (Briggs et al. 1981). California brown pelicans may forage at distances up to 75 km (45 mi) from their nesting colonies (Shannon 1933; Clapp et al. 1982), although most foraging occurs within 20 km (12 mi) of the nest site (Briggs et al. 1981).

Water

The dietary water requirements of brown pelicans can be satisfied by consumption of seawater (Schmidt-Nielsen and Fange 1958).

Nesting, Loafing, and Roosting Cover

Eastern brown pelican nesting colonies occur on coastal islands small enough to be free from human habitation and recreation and far enough from the mainland to be inaccessible to potential mammalian predators (Schreiber 1979; Williams 1979). Nesting colonies may abandon islands accessible to mammalian predators (Schreiber 1979).

Brown pelicans use both natural and man-made islands for nesting. In Florida, 20% of the breeding population nests on dredged-material islands (Schreiber and Schreiber 1978), reaching densities of 105 nests/ha (42 nests/acre) (Maxwell and Kale 1974). In addition, birds make extensive use of undisturbed dredged-material islands and sandbars for loafing and roosting (Schreiber and Schreiber 1982). Natural islands may be avoided because of their use by humans for recreation. Colony size (number of nests) is related to the amount of suitable nesting habitat. In areas where there are fewer islands with suitable nesting habitat, the average number of nests per colony is larger (Williams and Martin 1968).

Brown pelicans in the Carolinas and Texas nest on the ground or in small shrubs (Mendenhall and Prouty 1979; Clapp et al. 1982). In Louisiana, nests are built in black mangroves (Avicennia germinans) and on the ground (Blus et al. 1979a). Nests in Florida are usually constructed on open branches of mangrove trees (A. germinans, Rhizophora mangle, Laguncularia racemosa) 0.6 to 10 m (2 to 35 ft) above the ground, with the exception of one colony along the east coast consisting entirely of ground nests (Williams and Martin 1968; Schreiber 1978). Along the Florida gulf coast, nests are occasionally constructed in southern redcedar (Juniperus silicicola), redbay (Persea borbonia), seagrape (Coccoloba uvifera), and live oak (Quercus virginiana) (Williams and Martin 1970; Lovett E. Williams, Jr., Florida Game and Fresh Water Fish Commission; pers. comm.).

Brown pelicans nesting in trees are less vulnerable to flooding, human disturbance, and opportunistic predators than those nesting on the ground (Schreiber 1979; Lovett E. Williams, Jr., pers. comm.). When ground nesting occurs within the mangrove range, it is often on deteriorating islands where birds previously nested in trees (Schreiber and Schreiber 1978). Island elevation is important for nesting colonies outside the range of mangroves, where nesting is usually on the ground or in small shrubs. Nests on a colony's periphery are often flooded (Blus and Keahey 1978; Mendenhall and Prouty 1979). Potential nesting cover must be able to support a nest from 0.6 m (2 ft) to 10.7 m (35 ft) above the ground or high tide (Schreiber 1978).

Suitable branches for perching are important in nest site selection in mangroves (Schreiber 1977). Branches used for perching are usually within 1.2 m (3.9 ft) of the nest. Mangrove branches are also used in nest construction and are usually gathered from trees away from the nesting site. This results in areas of defoliation away from the colony but on the same island (Schreiber 1977). Distances between nests in mangroves are not less than 1.3 m (4.3 ft) or the distance neighboring pairs can reach while on the nest (Schreiber 1977). The number of active nests in colonies reported to the Colonial Bird Register (unpublished data) averaged 204 ± 32 nests per colony (Mean ± SE, N=99).

In Florida, Schreiber and Schreiber (1982) found that nesting adults may spend all of their nonforaging time on the colony island (Schreiber and Schreiber 1982). When not on the nests, they make use of sandbars and spits for loafing and roosting. These areas are essential drying sites for pelicans that become waterlogged after more than an hour on the water (Schreiber and Schreiber 1982). Older nestlings use vegetation and rocks on the island for shade during the hottest part of the day (Bartholomew and Dawson 1954), and new fledglings use the island for loafing and roosting (Schreiber and Schreiber 1982). Sandbars and spits are especially important to new fledglings that have not developed the coordination necessary to land on branches.

Although brown pelicans tend to use the same colony islands from one year to the next, factors such as proximity to food resources, human disturbance, predation, ectoparasites (see Special Considerations), and defoliation due to nesting activities may cause birds to shift breeding sites on a particular island as well as between islands from year to year (Williams and Martin 1968; Maxwell and Kale 1974; Schreiber and Schreiber 1982; Anderson and Gress 1983).

Establishment of a new colony on an island is preceded by use of that island for non-nesting activities (Schreiber and Schreiber 1982). Birds first use an island for loafing during the non-nesting season, then for roosting and loafing year-round, and then as a colony site. This progression of use may occur over a 3- to 4-year period (Lovett E. Williams, Jr., pers. comm.). Whether previous use is a necessary condition for establishment of a new colony has not been determined. Potential nesting habitat previously used for roosting and loafing is assumed to be more suitable than unused habitat.

Special Considerations

Several sources of human-induced stress can limit the productivity of brown pelicans. Organochlorines introduced into the food chain result in eggshell thinning (Blus et al. 1971; Blus et al. 1977; Mendenhall and Prouty 1979). Eggshell thickness was log-linearly related to DDE concentrations in eggs (Blus et al. 1972). Fat in starvation-stressed birds contained the highest levels of pesticide (Thompson et al. 1977). Some California colonies exposed to DDT-related compounds in food fish at concentrations of 4.3 parts per million have produced almost no young during the nesting season (Anderson et al. 1975). Organochlorines, particularly endrin, also have been implicated in the 1975 die-off of 150 adult birds (40% of the population) in Louisiana (Blus et al. 1979a).

The principal source of eastern brown pelican nesting failure is direct and indirect human interference with nesting colonies (Clapp et al. 1982). California brown pelican productivity (young per nest) may decline 52% to 100% as a result of one disturbance at the beginning of the nesting season (Anderson and Keith 1980). Eastern brown pelican nests disturbed two or more times per week have fewer eggs laid and reduced hatching success compared to nests disturbed once per week (Schreiber 1979). Flushing birds from nests allows avian predators like the fish crow (*Corvus ossifragus*) to destroy many eggs and young (Schreiber and Risebrough 1972). In addition, adults may not take time to step off the nest before flushing, resulting in crushed or displaced eggs or young. Nesting brown pelicans become alert to human presence within 100 m (328 ft) of the colony (Schreiber 1979), and loafing pelicans on colony islands prefer sandbars that are undisturbed by human activity.

Brown pelicans often scavenge food from fish-cleaning areas at marinas. Lincer et al. (1979) suggested that this unusual prey may have higher pesticide levels than the natural prey, which are fish lower in the food chain. Another hazard around marinas is entanglement in fishing lines, accounting for the deaths of more than 700 birds annually (Schreiber 1980b).

Oil spills cause an undetermined amount of mortality (Stevenson 1970). Adult mortality may occur at the time of the spill or after resuspension of oil accumulated in sediment (King et al. 1979). Hatching success may be reduced by oil contamination of eggs. Following an oil spill in North

Carolina, Parnell et al. (1983) found that 66% of the oil-contaminated eggs hatched, compared to 84% of unoiled eggs.

Another limiting factor to successful reproduction is ectoparasite load at the nest site. Excessive tick infestation in nesting areas has been implicated in the desertion of eggs and young by adult birds in Texas, California, and Peru (King et al. 1977b, 1977c; Duffy 1983). Ticks can number more than 700 per nest in severe infestations, can carry pathogenic viruses, and may cause birds to avoid the nesting area the following year.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

This model can be used to evaluate estuarine island habitat (Cowardin et al. 1979), natural islands, and dredge islands within the eastern brown pelican breeding range (Figure 1). The minimum habitat area required for breeding has not been established.

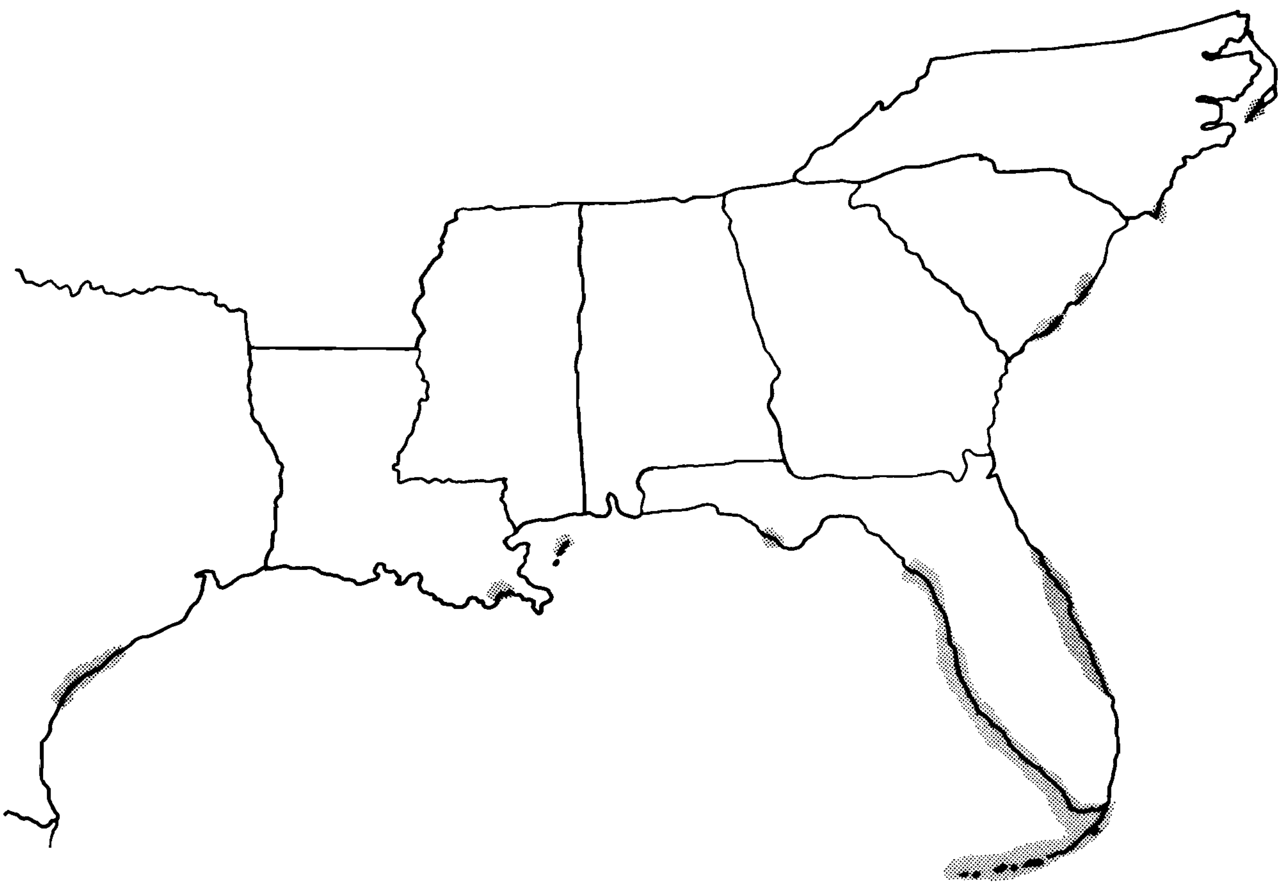


Figure 1. Breeding range of the eastern brown pelican and regions (shaded) of model applicability (Clapp et al. 1982).

Season. Eastern brown pelican breeding season can be year-round in southern Florida but tends to be late winter, spring, and/or early summer at more northern latitudes. The model should be used to evaluate breeding habitat at the beginning of the breeding season.

Verification level. The acceptable model output is an index value between 0.0 and 1.0 that reflects the habitat potential for eastern brown pelican nesting. A value of 1.0 indicates optimal suitability and 0.0 indicates unsuitability. The model has not been field-tested. Hypothetical data sets were used to verify that the model output was reasonable. Reviewers' comments have been incorporated, but the authors are responsible for the final version of this model.

Model Description

Overview. Components of the eastern brown pelican breeding habitat are nesting, roosting, loafing, and foraging sites. The quality of feeding sites around a colony may account for year-to-year variation in colony use and may limit the use of potential nesting habitat. Although the breeding success of California brown pelicans is dependent on food resources around their colony islands (Anderson et al. 1982), food distribution has not been incorporated as a variable in the eastern brown pelican habitat evaluation model because of lack of knowledge about the seasonal distributions of surface fish schools (see Schreiber and Schreiber 1983). Nesting, roosting, and loafing sites are evaluated by measuring habitat variables for the single life requisite of nesting/loafing cover (Figure 2). Use of this model assumes that the nesting habitat under evaluation comprises estuarine islands that do not support known populations of quadruped predators.

Nesting/loafing cover. Habitat variables in the model related to breeding habitat quality of an estuarine island are island surface area, distance from mainland, distance from human activity centers, and relative coverage of nesting vegetation.

The island surface area (V_1) and its distance from mainland (V_2) are assumed to be indications of its accessibility to quadruped predators. Islands larger than 8 ha (20 acres) may be able to support resident populations of predators (Landin 1978). Because brown pelicans are colonial nesters and mean colony size is probably 100 nests or more (Colonial Bird Register, unpublished data), the minimum area of highest suitability is assumed to be 2 ha (5 acres). This includes 1 ha (2.5 acres) of nesting area required by colonies of about 100 pairs at a density of 105 nests/ha (42 nests/acre), and 1 ha (2.5 acres) for loafing and drying.

Optimal distance from the mainland (V_2) is assumed to be 0.4 km (0.25 mi) or more, and suitability increases to a maximum at that distance (see Lewis 1983). Distance of islands from human activity centers (V_3) also influences habitat quality for nesting brown pelicans. Islands that have permanent human inhabitants or are visited by humans for recreational or commercial purposes during the breeding season are less suitable for nesting. Islands that are at least 100 m (328 ft) from areas of human activity may be used by brown pelicans for nesting, but suitability increases with distance to an optimum of

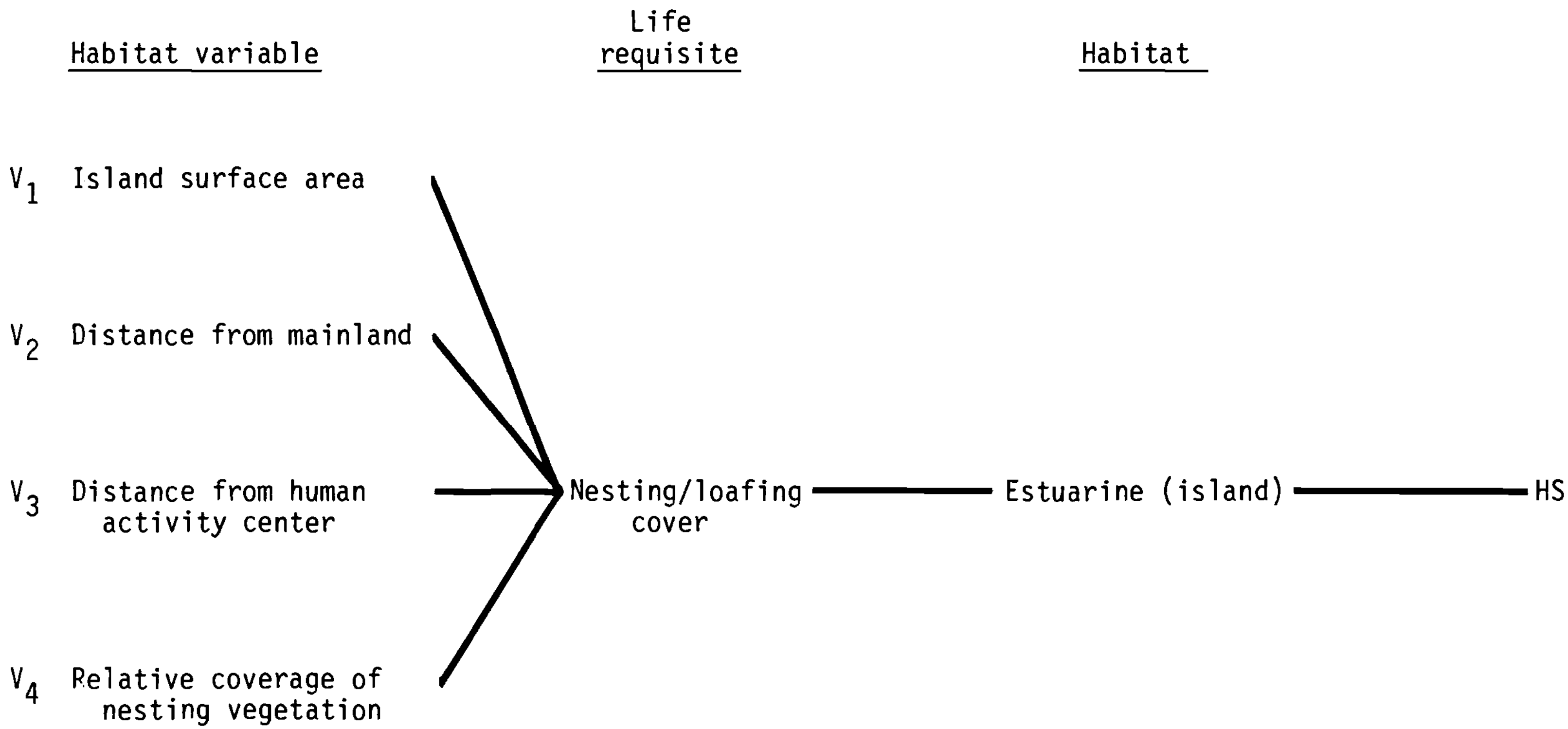


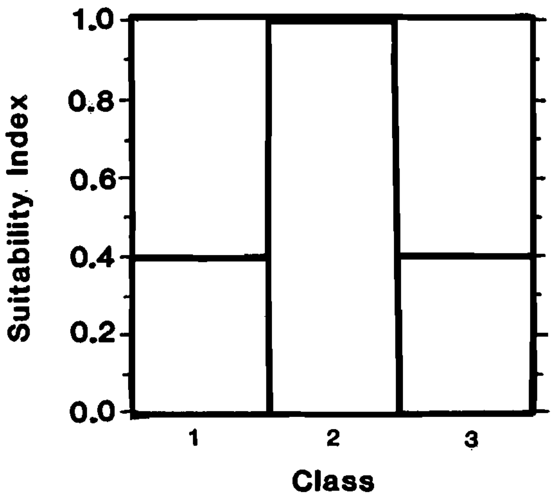
Figure 2. Relationships of habitat variables, life requisite, and habitat type in the HSI model for the eastern brown pelican.

0.4 km (0.25 mi) or more. This distance was chosen because it minimizes spurious visits by humans or their domestic animals.

Nesting cover (V_4) is identified differently for Florida, Alabama, and Louisiana than for Texas and the Carolinas. Where mangroves occur (FL, AL, LA), tree or shrub nesting is considered optimal for brown pelicans because nests can be constructed above high tide on low elevation islands, and pelicans are less vulnerable to human disturbance and opportunistic predators. Eastern brown pelicans nesting outside the mangrove range, including eastern Texas and the Carolinas, usually nest on the ground or in small shrubs. Island elevation is important for these colonies. Therefore, island surface and shrubs that are potential nesting cover must be at least 0.6 m (2 ft) above high tide. Nesting vegetation covering 50% or more of an island is considered optimal.

Suitability Index (SI) Graphs for Model Variables

The relationships between the habitat variables and breeding habitat suitability for brown pelicans are presented graphically in this section. The assumptions necessary to construct the model are summarized in Table 1. The SI values on the ordinate axis range from optimal habitat (1.0) to unsuitable habitat (0.0).

Habitat	Variable	Description	Suitability Graph
E	V_1	Island surface area 1) Less than 2 ha (4.9 acres) 2) 2 to 8 ha (4.9 to 19.8 acres) 3) Greater than 8 ha (19.8 acres).	

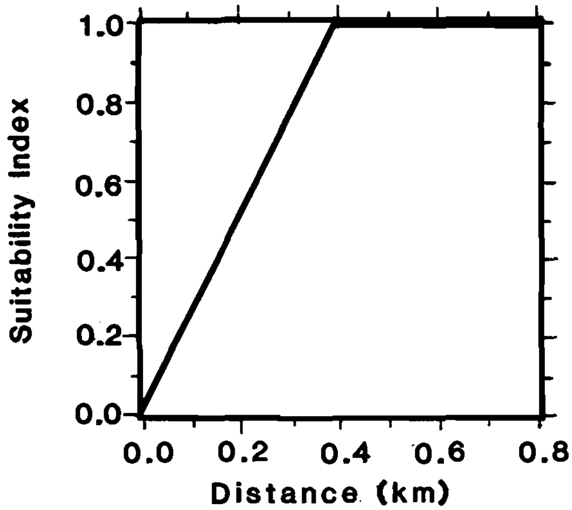
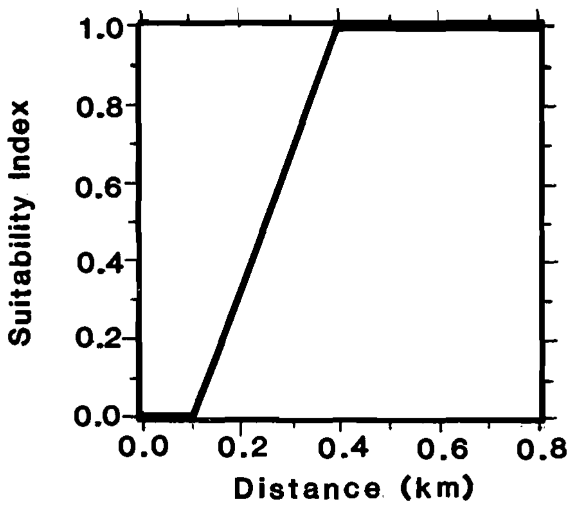
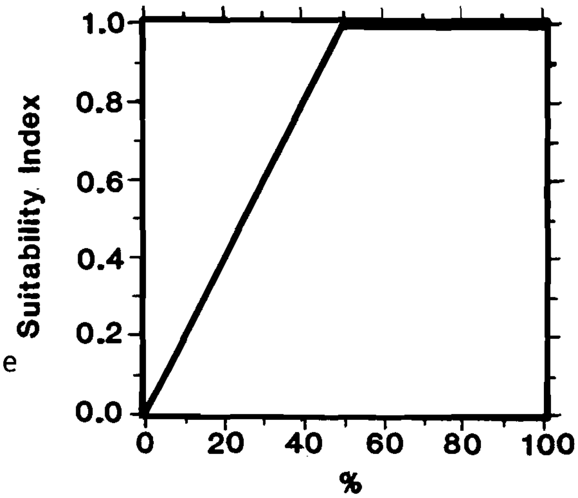
Habitat	Variable	Description	Suitability Graph
E	V_2	Straight-line distance of island from mainland.	
E	V_3	Straight-line distance of island from nearest human activity center.	
E	V_4	Relative coverage of nesting vegetation. Within the range of mangrove (FL, AL, LA), relative coverage is the percentage of the island supporting woody vegetation 0.6 to 10.7 m (2 to 35 ft) in height. Outside this range (NC, SC, TX), relative coverage is the percentage of the island surface area at least 0.6 m (2 ft) in elevation.	

Table 1. Sources of information and assumptions regarding breeding habitat variables used to calculate the HSI for eastern brown pelicans.

	Variable and sources	Assumptions
V_1	Landin 1978 Schreiber 1977 Colonial Bird Register, unpublished data	Islands that are 8 ha (20 acres) or larger are most likely to support resident populations of quadruped predators. Average colonies require at least 1.0 ha (2.5 acres) of nesting cover and a similar size sandy area for drying and loafing.
V_2	Schreiber 1979 Buckley and Buckley 1980 Briggs et al. 1981	Colony islands close to mainland are more accessible to mammalian predators. Islands that are 0.4 km (0.25 mi) or more from the mainland are virtually inaccessible. Island is assumed to be initially free of quadruped predators.
V_3	Williams and Martin 1970 Jehl 1973 Schreiber 1979 Schreiber and Schreiber 1982	Brown pelicans respond to human activity within 100 m (330 ft) of nesting colonies. One disturbance can disrupt production. Islands that are 0.4 km (0.25 mi) from the nearest center of human activity have less chance of being disturbed.
V_4	Nesbitt et al. 1977 Schreiber 1977, 1978 Blus and Keahey 1978 Schreiber and Schreiber 1978 Blus et al. 1979a	Tree heights of 0.6 to 10.7 m (2 to 35 ft) are optimal for nesting within the range of mangroves. Outside that range, ground nests higher than 0.6 m (2 ft) have a low risk of flooding.

Component Index (CI) Equation and HSI Determination

Nesting/loafing cover is the only life requisite considered in this model. Therefore, the HSI value equals the component index (CI) for cover. We suggest the following equation to obtain the CI and HSI values.

Component	Equation
Cover (C)	$(SI_{V_1} \times SI_{V_2} \times SI_{V_3} \times SI_{V_4})^{1/4}$

HSI = C

The output of the model is demonstrated for hypothetical data in Table 2. The first data set represents a situation where cover is limiting, while the second and third data sets represent situations where colonies are more vulnerable to predation and human disturbance.

Field Use of the Model

Suggested methods for measuring habitat variables are presented in Table 3. These methods were chosen for their efficient use of time and resources. If neither of these is limiting, methods producing a larger, more comprehensive data base may not only increase the precision of the model but may also provide information leading to its improvement.

Interpreting Model Output

When areas with similar HSI values are compared, an area previously used by pelicans for roosting and loafing is more likely to be used for nesting in the near future than an unused area. As with other HSI models, the HSI value obtained may have no relationship to nesting population size but indicates the potential of an area as nesting habitat.

Further studies of brown pelican ecology are necessary to provide information for model improvement. Especially needed are studies on nesting colony distribution relative to food fish distribution in surface waters, the effect of vegetation characteristics on nesting success, and the development of new colonies. Modifications and improvements should be incorporated as new data are collected.

Table 2. Model output of the component index (CI) and habitat suitability index (HSI) for three hypothetical data sets with their corresponding suitability index (SI) values.

Model component	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
V_1	2 ha	1.00	17 ha	0.40	4 ha	1.00
V_2	0.5 km	1.00	0.1 km	0.25	0.4 km	1.00
V_3	0.5 km	1.00	0.1 km	0	0.2 km	0.33
V_4	40%	0.80	50%	1.00	25%	0.50
C	0.95		0		0.64	
HSI	0.95		0		0.64	

Table 3. Suggested techniques for measuring breeding habitat variables for the brown pelican HSI model.

Habitat variable		Technique
V_1	Island surface area	Measure area of the island on a topographic map or aerial photo taken at high tide.
V_2	Distance from mainland	Measure straight-line distance from mainland shore to island shore at low tide.
V_3	Distance from nearest human activity center	Measure straight-line distance from closest area of any center of human activity to colony island. Identify the closest area of current human activity or projected human activity during the nesting season, whichever is the shorter distance.
V_4	Relative cover of nesting vegetation	Use aerial photos and topographic maps of estuarine islands to measure coverage of trees and shrubs 0.6 m (2 ft) to 10.7 m (35 ft) high (FL, AL, LA) or the area of island surface at least 0.6 m (2 ft) in elevation (NC, SC, TX). Visit islands to confirm vegetation physiognomy. Branches should provide nonsagging support of 6.5 kg (14 lb) (weight of two adults) at least 0.6 m (2 ft) above the ground.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a habitat model for the eastern brown pelican (*Pelecanus occidentalis carolinensis*). The model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1.0 (optimal habitat) for coastal areas within the eastern brown pelican's breeding range. Habitat suitability indices are designed for use with the Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for application of the eastern brown pelican habitat model and techniques for measuring model variables are described.

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Wildlife
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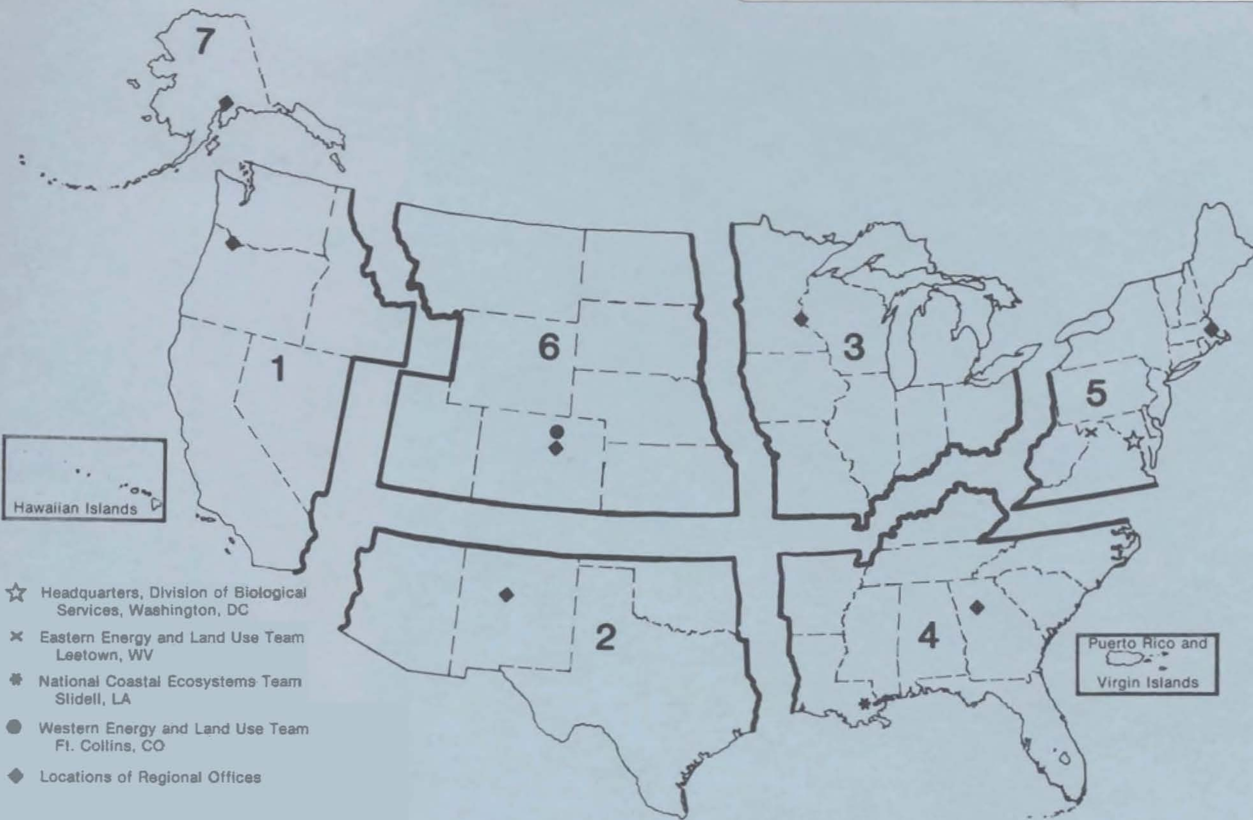

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